STATE OF ILLINOIS
ADLAI E. STEVENSON, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION
NOBLE J. PUFFER, *Director*

DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*
URBANA

REPORT OF INVESTIGATIONS—NO. 144

ATTERBERG PLASTIC LIMITS OF CLAY MINERALS

By
W. ARTHUR WHITE

REPRINTED FROM THE AMERICAN MINERALOGIST
VOL. 34, NOS. 7 AND 8, JULY-AUGUST, 1949

PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS
1949

ORGANIZATION

STATE OF ILLINOIS

HON. ADLAI E. STEVENSON, *Governor*

DEPARTMENT OF REGISTRATION AND EDUCATION

HON. NOBLE J. PUFFER, *Director*

GEOLOGICAL SURVEY DIVISION

M. M. LEIGHTON, Ph.D., *Chief*

This report is a contribution of the Division of Clay Resources and Clay Mineral Technology.

June 1, 1949

ATTERBERG PLASTIC LIMITS OF CLAY MINERALS*

W. Arthur White†

Abstract

The Atterberg plastic limits of the common pure clay minerals are presented. The data obtained indicate that the plastic limit of attapulgite>montmorillonite>illite >kaolinite; that the liquid limit of sodium montmorillonite>calcium montmorillonite =attapulgite>illite>kaolinite; and that the plastic index of sodium montmorillonite>calcium montmorillonite>attapulgite>illite>kaolinite. The data show also that all the Atterberg limits increase with decreasing particle size.

Introduction

The purpose of this report is to present the Atterberg plastic limits of pure clay minerals and the effect of the particle size of the clay minerals on the Atterberg limits. Because clay minerals are dominant components of most clay materials (soils, shales, tills, loesses, and clays), which are aggregations of particles of one or more clay minerals and frequently such non-clay materials as quartz, feldspars, organic matter, etc., the data on pure clay minerals should be very useful in interpreting data for natural clay materials. The Atterberg limits are widely used, particularly by engineers, as a means of estimating the plastic properties of clay materials.

Acknowledgments

The author is deeply indebted to the late Professor T. T. Quirke of the University of Illinois for his valuable advice and suggestions and to Drs. M. M. Leighton, Chief, and R. E. Grim, Head of the Division of Clay Resources and Clay Mineral Technology, for use of the facilities of the Illinois State Geological Survey.

Definition

The Atterberg limits of a soil or clay are the liquid limit, plastic limit, and plastic index, and Allen[1] defines them as follows:

1. "Liquid limit is the moisture content, expressed as a percentage by weight of the oven-dry soil, at which the soil will just begin to flow when jarred slightly."

2. "Plastic limit is the lowest moisture content, expressed as a per-

* Published with the permission of the Chief of the Illinois State Geological Survey. This report is an expanded part of a thesis on "The Properties of Clays" submitted in partial fulfillment of requirements for the degree of Master of Science in Geology in the Graduate School of the University of Illinois.

† Associate Geologist, Illinois State Geological Survey, Urbana, Ill.

[1] Allen, Harold, Classification of soils and control procedures used in construction of embankments: *Public Roads*, **22**, 263–265 (1942).

centage by weight of the oven-dry soil, at which the soil can be rolled into threads $\frac{1}{8}$ inch in diameter without breaking into pieces. Soil which cannot be rolled into threads at any moisture content is considered non-plastic."

3. "Plastic index is the difference between the liquid limit and the plastic limit . . . It is the range of moisture content through which a soil is plastic. When the plastic limit is equal to or greater than the liquid limit the plastic index is recorded as zero."

Procedure

The clay minerals, as determined by *x*-ray, differential thermal and microscopic analyses, were illites, kaolinites, montmorillonites, halloysites, attapulgite, and allophanes (Table 1).

The illites, the kaolinite from Union County, Illinois, and the montmorillonites from Mississippi were fractionated to less than 1.0 micron; also the illites (except the illite from Ohio) and the Union County kaolinite were fractionated to less than 0.5 micron. The remaining clays were not fractionated because they either would not disperse or they formed thixotropic suspensions.

The Atterberg limits were determined in accordance with Allen's[2] definition except that the liquid limit was determined in the Casagrande liquid limit machine as described by Casagrande.[3]

In determining the liquid and plastic limits of all the clay minerals except the montmorillonite from Belle Fourche, South Dakota, and attapulgite, the water was added to the clays until the plastic and liquid limits were reached.

The Belle Fourche montmorillonite, perhaps because it is the sodium type, requires different treatment because it forms a gel when water is *evenly* dispersed between the particles; whereas if water surrounds a lump, it will not penetrate to the interior because the outer surface will gel, forming an impermeable layer around the lump. It is, therefore, almost impossible to start with the dry clay and add water without forming lumps.

In order to get a smooth mixture of water and montmorillonite, the bentonite was added slowly to the water through a screen while the water was being stirred by a milk-shake machine. The montmorillonite was added until a gel was set up. This gel was stirred by moving the cup around the stirring blade to break up any lumps formed. The gel was

[2] Allen, Harold, *op. cit.*

[3] Casagrande, Arthur, Research on the Atterberg limits of soils: *Public Roads*, **13**, 121–130 (1932).

Table 1. The Atterberg Limits of Clay Minerals

Clay	Particle Size Microns	Plastic Limit	Liquid Limit	Plastic Index
Illite				
1. Grundy Co., Illinois	whole	35.70	61.20	25.50
	<1.0	39.59	83.00	43.41
	0.5	52.27	103.65	51.38
2. LaSalle Co., Illinois	whole	24.75	35.90	11.15
	<1.0	46.21	85.55	39.34
	0.5	52.98	111.25	58.27
3. Vermilion Co., Illinois	whole	23.87	29.05	5.18
	<1.0	44.44	95.05	50.61
	0.5	44.90		
4. Jackson Co., Ohio	whole	28.77	53.95	25.18
	<1.0	35.16	61.25	26.09
Kaolinite				
5. Union Co., Illinois	whole	36.29	58.35	22.06
	<1.0	37.14	64.20	27.06
	0.5	39.29	71.60	32.31
6. Twiggs Co., Georgia	whole	29.86	34.98	5.12
Montmorillonite				
7. Belle Fourche, S. Dakota	whole	97.04	625–700	528–603
8. Pontotoc, Mississippi	whole	81.41	117.48	36.07
	<1.0	109.48	175.55	66.07
Attapulgite				
9. Quincy, Florida	whole	116.64	177.80	61.16
Halloysite				
10. Halloysite, Eureka, Utah		not plastic		
11. Hydrated halloysite, Lawrence Co., Indiana		not plastic		
Allophane				
12. Lawrence Co., Indiana		not plastic		

poured into a pan and allowed to dry in air, the contents being stirred every day to keep an even and smooth mixture. Data were recorded when the montmorillonite became rigid enough to take 10 taps on the liquid limit machine and were continued to 50 taps.

The attapulgite had a gelling property similar to that of the sodium type montmorillonite, but it was not so pronounced. The same procedure was used to obtain the liquid limit of attapulgite as was used with the Belle Fourche montmorillonite.

Discussion

From the data (Table 1), the illites showed that with decrease in particle size the Atterberg limits increase. The illites from La Salle and Grundy Counties, Illinois, showed excellent correlation between particle size and the Atterberg limits. The Atterberg limits for the illite from Vermilion County, Illinois, indicated that most of the minus 1.0μ particles were near 0.5μ; whereas those for the illite from Ohio suggested that the particles were for the most part near 1.0μ in the minus 1.0μ fraction. The low Atterberg limits for the whole samples from La Salle and Vermilion Counties showed the influence of non-clay impurities as determined with the microscope. The plastic limit for an illite clay would probably range from 25 to 55 per cent; the liquid limit, from 50 to 115 percent; and the plastic index, from 25 to 60 per cent, with the variations depending upon particle size.

The kaolinites were represented by a very fine crystalline kaolinite from Union County, Illinois, and a very coarse crystalline kaolinite from Georgia. About 70 per cent of the Union County kaolinite was less than 0.5μ and most of the Georgia kaolinite was about 2μ. The kaolinites also showed the effect of particle size on the Atterberg limits, but these variations are not as great as for the illites. The plastic limit of kaolinite would probably range from less than 25 to 40 per cent; the liquid limit from 30 to 75 per cent; and the plastic index from 0 to 35 per cent. The shrinkage of the kaolinite would be less than that of the illites.

The montmorillonites were of two types: one carrying sodium as the exchangeable base (Belle Fourche, South Dakota) and the other carrying calcium (Pontotoc, Mississippi). The plastic limits of the two were about the same, but there was a great difference in the liquid limits which was probably due to the nature of the exchangeable base. The sodium montmorillonite set up gels which increased the liquid limit and also caused the results to be somewhat erratic. The calcium montmorillonite had a plastic index little greater than that of illite, but the plastic and liquid limits were considerably higher. Klinefelter et al.[4] reported the plastic

[4] Klinefelter, T. A., et al., Syllabus of Clay Testing, Part I, *U. S. Bur. Mines, Bull.* **451**, p. 7 (1943).

limit of montmorillonite as high as 250 per cent. The plastic range for this mineral would probably be 80 to 250 per cent; the liquid limit, from 115 to 700 per cent; and the plastic index, from 35 to 600+ per cent. This means that the montmorillonite upon drying would shrink considerably more than the illite.

The Atterberg limits of attapulgite are closely similar to those of the calcium montmorillonite. The shrinkage would be greater than that of illite and would probably about equal that of calcium montmorillonite.

Both the Eureka, Utah, halloysite, which was the lower hydrated form, and the Indiana halloysite, which was the higher hydrated form of this mineral, were nonplastic. However, work in progress suggests that some of the halloysites ranging between these two extremes are plastic.

The allophanes are amorphous hydrous aluminum silicates. The two samples used in this experiment were not plastic. However, it is possible that amorphous clay materials may be found that are plastic.

Conclusions

The data obtained on the plastic clays would indicate that the Atterberg limits increase with decreasing particle size. It would also indicate that the plastic limit of attapulgite > montmorillonite > illite > kaolinite; that the liquid limit of sodium montmorillonite > calcium montmorillonite = attapulgite > illite > kaolinite; and that the plastic index of sodium montmorillonite > calcium montmorillonite > attapulgite > illite > kaolinite. The shrinkage would probably be montmorillonite > attapulgite > illite > kaolinite.